

g. Establish Quantity-Distance (QD). Based on the final design of the facility and the types and NEQ of munitions to be stored and their distribution within the facility, the actual QD will be determined in accordance with procedures set forth in Chapter 9 of DoD 6055.9-STD. A final site plan for the facility which incorporates the QDs must be submitted for approval prior to construction.

#### 4. DESIGN CRITERIA

The following design criteria for underground ammunition storage facilities, and their components, have been developed and validated by research and analysis, and have been approved by the U.S. Department of Defense Explosives Safety Board (DDESB).

a. Types of Facilities.

1). A small magazine may consist of a single storage chamber and a coaxial entrance tunnel. It may also consist of a storage chamber that is located at an angle to the entrance tunnel. See sheet S-2 for examples.

2). A large underground facility will normally have several storage chambers and more than one portal. The layout of such a facility will depend on the site, topography, geologic conditions, storage quantity/compatibility, operational needs and safety considerations. See sheet S-1 for examples.

b. Components. The underground facility layout may consist of four fundamental types of components: chambers for storage or supporting operations, interconnecting tunnels, features designed to contain or reduce the hazardous effects of explosions, and utility and other systems required for operations.

1). Facility Layouts. The layout of the entrance/exit tunnels (and any secondary access passages) and the storage chambers will be determined by the minimum tunnel length needed to obtain the required chamber cover thickness, plus any additional length needed to accommodate loading/unloading chambers, expansion chambers, etc., or to reduce the explosion hazard levels at the portals. Minimum separation distances between storage chambers are based on requirements in Chapter 9 of reference DOD 6055.9-STD. The required chamber cover thickness must be measured along the shortest direct path between a chamber boundary (roof and wall) and the ground surface, and is the larger of the two values defined below:

d) The minimum required chamber cover thickness for a structurally stable chamber is dependant on the chamber width (span), the extent of arching in the cross-section of the chamber ceiling, the chamber support system, if any, and the structural strength of the rock above the chamber.

b) The critical chamber cover thickness required to prevent a catastrophic breaching (or rupture) of the cover by a detonation of the explosive contents of the chamber is dependent on the chamber loading density. See Chapter 9 of reference DOD 6055.9-STD.

2). Portal Structures. For portal construction, the in-situ material must be removed to provide a vertical face of rock of sufficient height to allow excavation of a stable tunnel opening. A reinforced concrete portal structure is normally constructed that, for unlined tunnels, extends into the tunnel opening far enough to adjoin competent, stable rock (normally a distance of one to ten meters). The headwall and wingwalls of the portal structure should extend far enough vertically and horizontally to prevent loose rockfall onto the portal entrance area.

3). Entrance/Exit Tunnels. For stability purposes, most tunnels have an arched ceiling. The height and width of an entrance tunnel must be sufficient to accommodate the passage of the largest vehicles and ammunition containers that will enter the facility. Depending on the size of the facility, these may range from pushcarts or hand trucks to two-way traffic of large transport trucks. Generally, the dimensions of the tunnel cross-section are controlled by the required width at the tunnel springline (i.e. where the vertical portion of the wall adjoins the base of the ceiling arch). The tunnel width must accommodate the width of the largest vehicle, plus a separation distance for any two-way traffic (if required), plus maneuverability room, plus space for single-file foot traffic along one wall. See sheet S-3 for examples. The crown of the tunnel arch must also be high enough to accommodate lighting fixtures and ventilation ducts above the required clearance height of the largest vehicles. These utilities will normally be located above the tunnel springline.

4). Loading/Unloading Chambers. Large facilities may have an interior chamber for unloading or loading ammunition transport trucks. See Sheet S-1 for example. To minimize the width requirements of such a chamber, the traffic flow will normally be one-way, with vehicles entering one end of the chamber and exiting from the other end. The exit tunnel may lead to a second portal, or may loop back to intersect the entrance tunnel, with two-way traffic from that point to a single entrance/exit portal.

The width of a loading/unloading chamber must be sufficient for one lane of parked trucks, one thru-lane for bypassing parked trucks, and operating room for forklifts, gantry crane with electrically operated hoist, or other MHE used to load and unload the munitions. See Sheet S-3. Since a loading/unloading chamber will be wider than the entrance tunnel, the chamber height should be that required to provide a stable ceiling arch across the width of the chamber. The required length of a loading/unloading chamber will depend on the number of vehicles expected to be parked at any one time, plus the extra distance needed to pull into or out of a parking space.

5). **Storage Access Tunnels.** In large facilities, storage access tunnels lead from loading/unloading chambers (or other internal rooms) to the storage area (see sheet S-1). As an alternative, the storage access tunnel may be designed to allow transport trucks to be loaded or unloaded in front of the individual chamber entrance tunnels. In these facilities, the storage access tunnel must be designed like an entrance/exit tunnel.

6). Chamber Entrance Tunnels. Chamber entrance tunnels will normally be used only by hand trucks, dollies, or forklifts for moving munitions from the storage access tunnel or from the loading/unloading chamber to the individual storage chambers. The widths of these tunnels are based on the width of the MHE and/or large ammunition containers plus a separation distance for two-way traffic, plus maneuverability room, plus space for single-file foot traffic. The height of these tunnels must be based on the height of the MHE, particularly a forklift in the raised, transporting position. Again, adequate heights must be allowed for lighting and ventilation ducts above the equipment height.

7). Storage Chambers.

a) The size and shape of the munition storage chambers are based on the allowable NEQ per chamber, the bulk volume of the munitions, and the engineering properties of the rock in which a chamber is excavated. For munitions such as rockets and missiles, the bulk volumes will be many times greater than those of munitions with large explosive weights, such as 155mm M107 artillery projectiles. The required floor area of a storage chamber will also depend on the "stackability" of the packaged munitions and the operating room required by the MHE that stacks them.

b) A reasonable minimum chamber width to accommodate stacking space and MHE maneuver room is about 10 meters. The maximum chamber width is normally limited by the free span width that can be excavated in the rock and remain structurally stable. Chamber widths of 20 to 30 meters can be constructed in very strong rock types, but the ceiling heights required to provide a stable arch results in excavation volumes that increase roughly as the square of the chamber width. From an engineering standpoint, there is essentially no limit to the chamber length that can be excavated. Consequently, chambers with large storage capacities may have lengths up to six or eight times the chamber width, in order to maximize the storage volume while maintaining a stable chamber.

c. Hazard Reduction Features. Hazard reduction features are designed to contain or mitigate the hazardous effects of an explosion, such as airblast, debris (fragments), and thermal effects. The use of one or a combination of these control features will greatly reduce the external hazards. Use of barricades in conjunction with any other hazard reduction feature will lower the debris hazard to a level where QD considerations for debris will not be required.

1). Barricades

a) A barricade, if required, shall be located in front of a portal and centered on the extended axis of the tunnel. The face of the barricade toward the portal shall be vertical and concave in plan. The barricade shall have a vertical face, oriented perpendicular to the tunnel axis, with wingwalls on either side of the face that are angled at 30 to 60-degrees toward the portal. The width of the barricade face (excluding wingwalls) shall intercept an angle of at least ten degrees to the right and left of the extended tunnel width. The height of the barricade along its entire width shall intercept an angle of at least ten degrees above the extended height of the tunnel. See Sheet S-4 for barricade orientation.

b) The barricade shall be located a distance of not less than one and not more than three tunnel widths from the portal. The actual distance should be no greater than that required to allow passage of any vehicle or material handling equipment (MHE) that may need to enter the tunnel. The distance shall be based on the turning radius and operating width required for the vehicle or MHE.

c) The front face of the barricade (excluding wingwalls) shall be constructed of reinforced concrete, with a minimum thickness of 0.305 meters or a thickness equal to 10 percent of the barricade height, whichever is greater. The concrete wall shall have a spread footing of sufficient width to prevent significant settlement, and the central wall, wingwalls, and footing must be structurally tied together to provide stability. See Sheet S-5 for example of a barricade design. The backfill behind the concrete wall may be composed of any

fill material, including rock rubble from the tunnel excavation, with a maximum particle size of 150mm within the area extending out to three feet from the rear face of the wall. An engineering analysis should be performed to ensure that the barricade will remain in place based on the maximum shock wave from a storage chamber detonation that exits a tunnel portal.

2). Debris Traps.

Debris traps are pockets excavated in the rock at or beyond the end of tunnel sections, and are designed to entrap debris blown through the tunnel from an explosion. The total volume of all debris traps and expansion chambers between a storage chamber and any portal should be sufficient to contain the full potential volume of debris from a detonation in that storage chamber. Debris traps should be at least 20 percent wider and 10 percent taller than the tunnel leading to the trap, with a depth of at least one and a half times the tunnel diameter.

### 3). Expansion Chambers.

Expansion chambers are large rooms located between the storage chamber(s) and the tunnel entrance(s), having a cross-sectional area at least three times as great as that of the largest tunnel intersecting the expansion chamber, and a length that is at least as great as the expansion chamber width. For the chamber to be effective in entrapping debris, the tunnels entering and exiting the chamber must be offset in axial alignment by at least two tunnel widths, or enter and exit the chambers in directions that differ by at least 45 degrees.

#### 4). High-pressure Closures.

High pressure closures are large blocks constructed of steel, concrete and/or other materials, that can obstruct or greatly reduce the flow of the airstream and debris from an explosion in a storage chamber. The block must be designed to remain structurally intact and of sufficient mass to obstruct the outflow of airstream following an explosion in that chamber to reduce pressures in the connecting tunnels. A design analysis for the closure block must be provided to DDESB for approval. The two closure block concepts that have been tested are:

a. MAGAE Block. This block is designed to be rapidly driven from an open to a closed position by the detonation pressures in the chamber. Because the block is normally in an open position, a blast door must be provided at the entrance to the storage chamber to provide protection from an explosion elsewhere in the facility. See Sheet S-6 for an illustration of the MAGAE block configuration.

b) KLOTZ Block. This block is designed to be moved by mechanical mechanisms from closed-to-open and open-to-closed position. The block is in the closed position during long term storage. The block is in the open position when operations are being performed in the storage chamber and will rapidly close in the event of an explosive accident. A blast door is not required with this type of closure, as the block is normally in the closed position.

5). Tunnel Constrictions. A constriction is a short section of tunnel with a reduced cross-section. The minimum length of a constriction is 1.5 times the tunnel diameter. If located within five (5) tunnel diameters of a portal, a constriction reduces the external airblast by providing a smaller hydraulic diameter of the exit, as used in the equation for external overpressure in Chapter 9 of reference DOD 6055.9-STD. Constrictions may also be located at chamber entrances to reduce the size of blast doors or closure blocks, but do not contribute to hazard reduction at these locations.

6). Blast Doors. To prevent propagation and protect assets, blast and fire resistant doors shall be provided within multichambered facilities (except as noted above). The design load for all blast doors should be based on the maximum airblast pressure and impulse at the door location, as calculated using the computer program BLASTX, or an equivalent code approved by the DDESBS. The BLASTX computer program may be obtained from US Army Engineer Waterways Experiment Station, CEWES-SD, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199. A blast door is normally provided by a single manufacturer as a complete assembly including the door, frame, hardware, and accessories. U.S. Army Corps of Engineers Guide Specification for Military Construction, CECS-13977, Blast Resistant Doors, should be included as a performance specification of individual door assemblies, the door type, blast effects, rebound, deformation limits, operating forces, hardware, and accessories. Discussed below are some of the blast door requirements.

a). Door Size and Type. The doors shall be large enough to accommodate the passage of the MHE and/or the ammunition container. Door types available include single leaf , double leaf or sliding doors.

b). Blast Door Material. Selection of material shall be based on availability, operability and economics. Steel, concrete, or hollow metal doors may be used, based on the blast-induced loading.

c). Performance Criteria. Furnish blast door assembly and frame to meet the triangular pressure-time loading.



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UNDERGROUND AMMUNITION STORAGE FACILITY  
GENERAL NOTES

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Page 2 of 2